How Does Plant Population Density Affect the Forage Yield of Eastern Gamagrass?

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ABSTRACT

Eastern gamagrass [*Tripsacum dactyloides* (L.) L.] is a perennial, warm-season bunchgrass native to the Americas. Although much is known about the effects of fertilization and harvest frequency on the yield of eastern gamagrass, information on the effects of plant density on yield is lacking. Our objectives were to investigate the effects of plant population density on annual dry matter (DM) yield, vegetative shoot density, and basal area of plant crowns of irrigated eastern gamagrass. Cumulative forage DM yield varied significantly with year $\times$ density interactions ($P < 0.01$). Higher plant densities produced greater DM yields with the highest sustained forage yields obtained at a density of 4.8 plants m^{-2}. Variation in number of vegetative shoots per square meter was attributed to year ($P < 0.05$) and density ($P < 0.01$). Higher plant densities also had a greater number of vegetative shoots; however, plots with higher initial stand densities reached equilibrium much faster than plots with lower stand densities. Variation in crown area was associated to year $\times$ density interactions ($P < 0.01$). Mature shoots near the edge of the crown probably produce a greater number of tillers until an equilibrium is reached. This is suggested by our data where the number of vegetative shoots per plant increased with decreasing plant density. Most planting recommendations for eastern gamagrass call for seeding into wide rows. These recommendations were developed to enhance seed production stands and facilitate the use of field equipment. Narrower row spacings may facilitate stand establishment while increasing forage production early in the life of the stand.

Eastern gamagrass is a highly productive and palatable forage grass that can be grown throughout the Southern Plains and the eastern USA. The number of hectares grown has increased during the past decade with renewed interest in its use for pasture production and soil conservation. The effects of harvest frequency and N fertilization of eastern gamagrass on yield is well documented (Brejda et al., 1996, 1997); however, information on the effects of plant density on yield is lacking. Brejda et al. (1996) reported a curvilinear response in forage production as N rate increased with yield peaking near 10 600 kg ha^{-1} with 224 kg N for plots harvested at 6-wk intervals at Elsberry, MO, and a linear response in forage yield with forage production continuing to increase at the same N level at Clifton Hill, MO. They also reported that three or four harvests were possible during the growing season with a 4-wk harvest interval and that two or three harvests were possible with a 6-wk interval. They further reported that crude protein concentration of forage harvested at a 4-wk interval averaged 131 g kg^{-1} compared with 97 g kg^{-1} for a 6-wk interval and that total forage production was higher for plots harvested at 6-wk compared with 4-wk intervals.

The effects of plant population density on horticultural and field crops is well established (Wade et al., 1988; Boquet, 1990; Hintz and Fehr, 1990; Wade and Douglas, 1990; Lege et al., 1993; Lauer, 1995; Cuomo et al., 1998; Cusicanqui and Lauer, 1999). In contrast, very little is known about the effects of plant density on the yield of native forage grasses or other forage species (Bolger and Meyer, 1983; Cooksley and Goward, 1988; Graybill et al., 1991; Pinter et al., 1994; Jefferson and Kielly, 1998; Sanderson and Reed, 2000). For field crops such as corn (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], and soybean [*Glycine max* (L.) Merr.], grain yields are generally maximized by adjusting the planting densities to the moisture conditions (Jones and Johnson, 1991; Sanderson et al., 1996). Densely populated stands utilize available moisture and nutrients more quickly than sparsely populated stands (Jones and Johnson, 1991).

Plant morphology is also affected by plant density. Skalova and Krahulec (1992) found that as plant density increased, tiller numbers of *Festuca rubra* L. decreased. Similarly, Hiernaux et al. (1994) found plant tillering compensated for low plant density that resulted from drought or intense grazing. Most of the information available on the effects of plant density on forage quality and feeding value is from tropical forage corn or forage sorghums (Pinter et al., 1994; Sanderson et al., 1996; Cuomo et al., 1998; Cusicanqui and Lauer, 1999).

Understanding the growth and development of native, warm-season grasses at varying population densities will improve forage management, production, and utilization. The objectives of this study were to determine the effects of plant population density on the DM yield, vegetative shoot density, and basal area of plant crowns of irrigated eastern gamagrass.

MATERIALS AND METHODS

This study was conducted at the USDA-ARS, Southern Plains Range Research Station, Woodward, OK (36°25′ N, 99°24′ W, elevation 615 m) on a Carey silt loam (Fine-silty, mixed, superactive, thermic Typic Argiustolls). Plants of eastern gamagrass accession WW-1000 were subdivided into ramets consisting of a single shoot with root to ensure a uniform plant material for transplanting. Accession WW-1000 is a locally adapted strain of eastern gamagrass collected on the Southern Plains Range Research Station in 1971, and is similar to other naturally occurring populations of eastern gamagrass found in western Oklahoma and the Texas panhandle. Ramets from this accession were transplanted in early March 1976 into four blocks (replications) consisting of four variable sized plots (treatments). Variable plot sizes were used to obtain the desired plant population densities. The treatments consisted

Abbreviations: DM, dry matter.

Table 1. Actual plot dimensions, plant spacing within plot, number of plants per plot, harvested area, and number of plants harvested per plot for eastern gamagrass transplanted at four population densities.

Plant density	Plot dimensions		Plant spacings		Plants per plot	Harvested area	Plants harvested
	Width	Length	Row width	Within row			
plants m^{-2}			m		n	m^{-2}	n
1.2	3.65	6.40	0.91	0.91	28	8.36	10
2.4	2.74	4.57	0.45	0.91	30	5.02	12
4.8	2.74	3.20	0.45	0.45	42	4.18	20
10.7	2.74	3.35	0.30	0.30	80	4.46	48

of four population densities representing 1.2, 2.4, 4.8, and 10.7 plants m^{-2}. The actual plot dimensions, plant spacing within a plot, number of plants per plot, harvested area, and number of plants harvested per plot are given in Table 1.

During the establishment year, plots were maintained weed-free by hoeing and dead plants were replaced to maintain population densities. The second year, 1977, plots were trimmed back in early June and the forage was harvested in late July. After harvest, plots were fertilized with ammonium nitrate at the rate of 170 kg N ha^{-1}. From 1978 through 1982, plot management included weed, fertilization, irrigation, and harvest managements as described below.

Weed management. Plots were burned the last week of March and maintained weed-free by hoeing the rest of the season.

Fertilization management. Ammonium nitrate fertilizer was applied at the rate of 95 kg N ha^{-1} at spring green-up (about 10 April), after the first harvest (about 1 June), and after the second harvest (about 15 July). After each fertilization, ≈12 mm of irrigation was applied to activate the fertilizer. In addition, 280 kg ha^{-1} P$_2$O$_5$ was applied in 1979 at spring green-up.

Irrigation management. During the period from April through September, a target of 25 mm wk^{-1} of water was supplied from either rainfall, irrigation, or both. The majority of irrigation, an average of 257 mm, was supplied during the months of June, July, and August to supplement a yearly average rainfall of 427 mm.

Harvest management. Plots were harvested three times each year except in 1977 when plots were harvested only once (Table 2). Target harvest dates were 1 June, 15 July, and 1 September each year, giving a 45-d harvest interval. The desired number of plants per plot (Table 1) were harvested by clipping a 1.83-m swath from the center of each plot. The distance harvested varied with plant population density. Harvested forage was placed into burlap bags and oven dried at 65°C until dry (≈72 to 96 h). The forage DM yield of each plot was converted to DM yield in kilograms per hectare.

Crown area was determined by measuring four plants in each plot in mid-April of 1979 and 1982. Each plant diameter was measured twice, once in the east-west direction and again in the north-south direction. These two measurements were averaged to determine a plant's diameter and crown area. At that same time, the number of vegetative shoots per plant was counted for the same four plants mentioned above.

Data for DM yield were analyzed with a split plot in time

ANOVA (Steel and Torrie, 1980). The main-plot factor was plant density and the subplot factor was harvest. Plant density, harvest, and year were treated as fixed effects because we wanted to discuss the data for a particular set of years (environments). Data for cumulative DM yield, crown area, and number of vegetative shoots per plant were analyzed with a randomized block ANOVA with years combined (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Harvest Effects on Yield

Forage DM yield of eastern gamagrass varied significantly with harvest × year interactions ($P < 0.01$). There were no harvest × density interactions ($P = 0.58$) or year × harvest × density interactions ($P = 0.85$). Harvest effects accounted for 60% of the total variation in yield, year effects accounted for 13%, and year × harvest interactions accounted for 10%. Plots harvested on or near 1 June averaged 5760 ± 120 kg ha^{-1} (mean ± SE), on or near 15 July averaged 3450 ± 120 kg ha^{-1}, and on or near 1 September averaged 2540 ± 90 kg ha^{-1}. On the basis of standard errors of means, variation was equal for the 1 June and 15 July harvests, which was greater than the variation for the 1 September harvest. Following forage removal, it is common for leaves of eastern gamagrass to elongate at a rate of 3 to 5 cm d^{-1} (Springer and Dewald, 2004). Differences in actual harvest intervals (Table 2) may account for much of the variation in harvests, as well as ambient temperatures and irrigation management. All of these factors could help to explain the year × harvest interaction.

In the Southern Plains it is possible to make three harvests annually of eastern gamagrass with supplemental irrigation with a 45-d harvest interval. Without supplemental irrigation, the norm would be two harvests (Springer, 2002, unpublished data). Similarly, without supplemental irrigation, Brejda et al. (1996) found that two or three harvests were possible with a 42-d harvest interval in the higher precipitation midwestern region of the USA. They found also for study years 1992 and 1993, that the second and third harvests combined ac-

Table 2. Actual dates for harvesting eastern gamagrass at Woodward, OK, in 1977 to 1982. The target harvest dates were 1 June, 15 July, and 1 September of each year.

Harvest	Year of harvest					
	1977†	1978	1979	1980	1981	1982
1		31 May	29 May	5 June	2 June	11 June
2	26 July	13 July	18 July	23 July	15 July	15 July
3		1 Sept.	27 Aug.	30 Aug.	1 Sept.	2 Sept.

† The first year after establishment, plants were allowed to accumulate forage until what would normally be considered a second harvest. This was done to maintain the health and vigor of the establishing plant stand.
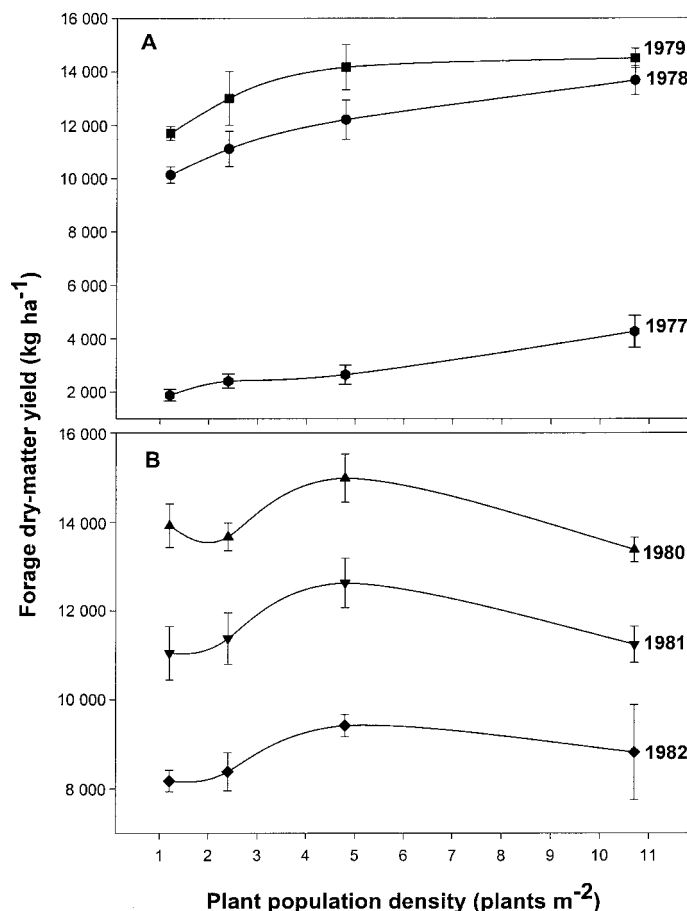
Fig. 1. Relationship of plant population density and cumulative forage dry matter yield of eastern gamagrass grown at Woodward, OK, from 1977 to 1982. (A) Growth phase. (B) Transition from growth phase into an equilibrium phase. Each data point is the mean ± SE of four experimental units. Point-to-point splined lines were added to aid in data interpretation.

counted for 40 to 72% of the total forage yield, depending on applied N rate and location of experiment. In contrast, we found with supplemental irrigation the second and third harvests combined accounted for 50 to 59% of the total harvest. Supplemental irrigation use will reduce year-to-year variability in forage production systems.

Plant Density Effects on Forage Yield and Number of Vegetative Shoots

Cumulative forage DM yield varied significantly with year × density interactions ($P < 0.01$). When exploring the year × density interaction, two patterns emerge for the effects of plant density on cumulative forage DM yields. The first 3 yr of data, 1977 to 1979, suggest a growth phase (Fig. 1a), while the last 3 yr of data, 1980 to 1982, suggest a transition from the growth phase into an equilibrium phase (Fig. 1b).

Variation in number of vegetative shoots per square meter was attributed to year ($P < 0.05$) and density ($P < 0.01$) effects. At the onset of the experiment in 1976, plant crowns consisted of a single vegetative shoot, thus giving a linear relationship between plant density and number of vegetative shoots per square meter. In 1979 and 1982, this linear relationship gave way to curvi-

linear relationships between plant density and number of vegetative shoots per square meter (Fig. 2).

We separated the effects of plant density on forage yield of eastern gamagrass into the growth or equilibrium phases. The growth phase is characterized by crown development and expansion of the crown to occupy available space both above and below ground level. Once this occurs, the crown transitions into equilibrium and growth is limited by competition for nutrients. At a plant density of 10.7 plants m^{-2}, equilibrium in forage yield was reached by 1979, the second year after establishment. Yield peaked at 14 850 kg ha^{-1} ± 410 (Fig. 1a) and that the number of vegetative shoots per square meter in 1979 (429 ± 38 shoots m^{-2}) did not significantly differ from that in 1982 (419 ± 38 shoots m^{-2}, Fig. 2). Equilibrium for other density treatments was reached when the density of vegetative shoots was not significantly different from the number of vegetative shoots per square meter in the 10.7 plants m^{-2} density treatment. On the basis of this criterion, the 2.4 and 4.8 plants m^{-2} density treatments reached equilibrium by 1982. Plots with higher plant densities were expected to reach equilibrium sooner because nutrient resources, other than annually applied N and periodically applied P in our experiment, are depleted more quickly with higher
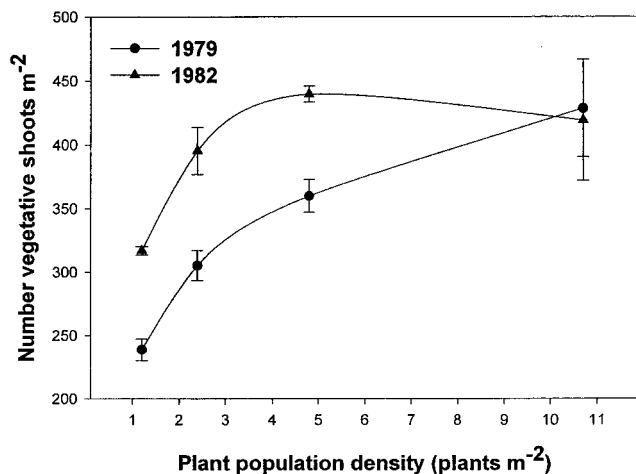
Fig. 2. Relationship of plant population density and number of vegetative shoots per square meter of eastern gamagrass grown at Woodward, OK, for 1979 and 1982. Each data point is the mean ± SE of four experimental units. Point-to-point splined lines were added to aid in data interpretation.

plant densities, thus limiting plant growth (Jones and Johnson, 1991).

Another important aspect of this experiment was the reduction in yield that began in 1981. Although, some center *die out* was observed in plant crowns toward the end of this study, this alone could not explain the reduction in yield across all density treatments. Eastern gamagrass under high fertilization and optimum rainfall condition contains 2.24% N, 0.27% P, and 2.06% K on a dry weight basis (Natural Resources Conservation Service, 1998). On the basis of these numbers, the amount of N required to produce an average first harvest yield of 5760 kg ha^{-1} is 129 kg; an average second harvest yield of 3450 kg ha^{-1} is 77 kg; and an average third harvest yield of 2540 kg ha^{-1} is 57 kg. Similarly, P requirements for the first, second, and third harvests are 16, 9, and 7 kg ha^{-1}, respectively, and K requirements for the first, second, and third harvests are 119, 71, and 52 kg ha^{-1}, respectively. We applied N at the rate of 95 kg ha^{-1} at spring green-up and again after the first and second harvests (285 kg N ha^{-1} annually), and P at the rate of 122 kg ha^{-1} in the third year of the experiment. Although we were applying sufficient N for the total yearly production, targeting the first harvest with 150 kg N ha^{-1}, the second with 75 kg ha^{-1}, and the third with 60 kg ha^{-1} would better match the annual utilization of N. An application of P at 122 kg ha^{-1} during the third year of the experiment compensated for the annual requirement of 32 kg ha^{-1}. However, no supplemental K was applied, thus decreasing soil nutrient levels of K ≈242 kg ha^{-1} annually. It would probably be better to apply P and K annually rather than periodically as specified by a soil test of these nutrients and apply all nutrients proportionally to harvest needs. Fertilization requirements for nonirrigated eastern gamagrass would be different from these recommendations and would need to be researched; however, applying nutrients according to the plant's needs should probably be done.

Density Effects on Crown Morphology

Variation in crown area and vegetative shoots per plant were associated with year × density interactions ($P < 0.01$). Crown growth, measured by crown area or number of vegetative shoots per plant, followed curvilinear relationships regardless of plant density (Fig. 3). At planting in 1976, plant crowns consisted of a single vegetative shoot. The estimated crown area of a single shoot is 3 ± 1 cm^2. In addition, a single shoot consists of a mature phytomer with 1 or 2 roots and 2 to 4 flanking tillers (Dewald and Louthan, 1979). In 1979, crown area varied from 129 ± 17 cm^2 for 10.7 plants m^{-2} to 672 ± 22 cm^2 for 1.2 plants m^{-2} (Fig. 3a). In 1980, crown area varied from 351 ± 8 cm^2 for 10.7 plants m^{-2} to 1440 ± 52 cm^2 for 1.2 plants m^{-2} (Fig. 3a). The number of vegetative shoots per plant in 1979 varied from 40 ± 4 to 198 ± 7 (Fig. 3b). In 1980, the number of vegetative shoots per plant varied from 39 ± 9 to 264 ± 3 (Fig. 3b). Skalova and Krahulec (1992) found that tillering in *F. rubra* increased as plant density decreased, and Hiernaux et al. (1994) found that the main purpose of tillering was to compensate for low plant density. This probably occurs in eastern gamagrass as well. As the plant crown expands, new growth takes place at the leading edge, that is, the perimeter of the crown. Nutrient levels within the crown area are presumably lower than outside the crown area, thus causing an outward growth. Shoots within the crown may be smaller and produce fewer tillers because of lowered nutrient availability and the density of the crown. Shoots along the outer edge of the crown probably produce a greater number of tillers until an equilibrium is reached. This is suggested by our data in Fig. 3, where the number of vegetative shoots per plant increases with decreasing plant density. Once depleted of nutrients, the center of the crown, in a weakened state, is susceptible to invasion by insects and saprophytic organisms which aid in the decomposition of the dead crown base. As stated earlier, some center *die out* was observed in plant crowns toward the end of this study; however, most was associated with the plots established at 1.2 and 2.4 plants m^{-2} and not those established at 4.8 or 10.7 plants m^{-2}.

CONCLUSIONS

Plant population density affects the forage yield of eastern gamagrass in at least three ways. First, as plant density is increased forage DM yields increase, especially during the early years of stand establishment. The highest sustained forage DM yields after stand equilibrium was with a 4.8 plants m^{-2} stand density. Second, plant density affects the number of vegetative shoots per square meter. Early in the life of the stand, higher plant densities have a greater number of vegetative shoots; however, plots with high stand densities reached equilibrium much faster than plots with lower stand densities. Third, plant density affects the rate of crown expansion. The number of vegetative shoots per plant was greater for lower plant densities. Presumably, plants at lower densities produce a greater number of tillers
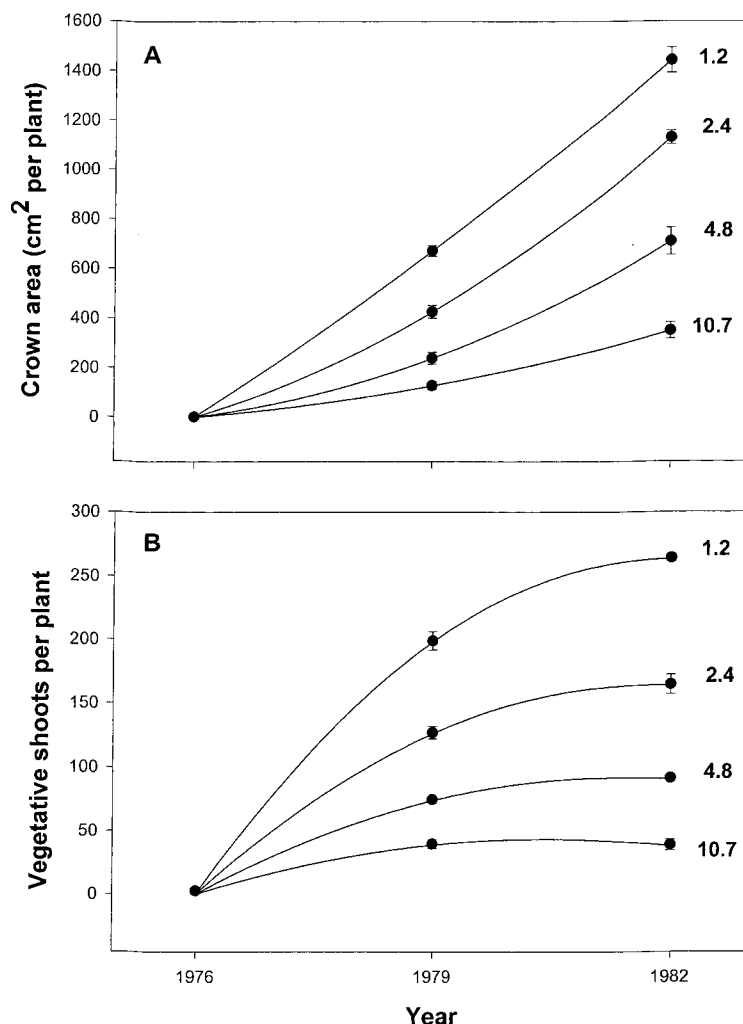
Fig. 3. Relationship of plant population density and (A) crown area and (B) number of vegetative shoots per plant for eastern gamagrass grown at Woodward, OK, from 1976 to 1982. Each data point is the mean ± SE of four experimental units. Point-to-point splined lines were added to aid in data interpretation.

and thus compensate for their low density. Lastly, in our experiment the plant density affects were the same regardless of harvest or year of harvest. This was evident by the lack of harvest × density interactions and year × harvest × density interactions.

Other considerations of our experiment are that N, P, and K requirements for irrigated eastern gamagrass should be monitored closely by soil testing. Nutrient amendments should be applied to meet the needs of the individual harvests rather than the entire growing season.

Most planting recommendations for eastern gamagrass call for seeding 11.2 kg ha^{-1} of pure seed into wide rows (0.9 to 1.2 m). These recommendations were developed primarily for seed production stands where wider row spacings facilitated the use of cultivating and harvesting equipment. Narrower row spacings and slightly higher seeding rates may hasten stand establishment for increased forage production early in the life of the stand.

ACKNOWLEDGMENTS

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